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1992



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Recuay style painted textile, Peru, ca. 200 B.C.–A.D. 400, 206 cm x 100 cm. The Textile Museum 1962.30.6. See "A Recuay Style Painted Textile," Nancy Porter, pp. 71–81. Photo by Franko Khoury.

Note to contributors

The Textile Museum Journal is devoted to the presentation of scholarship concerning the cultural, technical, historical, and aesthetic significance of textiles. The Journal is international in scope with emphasis on textile traditions represented in The Textile Museum collection, which is drawn from Near Eastern, Asian, African, and indigenous American cultures.

Authors are invited to submit manuscripts based on original research of a documentary, analytical, or interpretive nature. Articles should be both scholarly and accessible to a broad readership.

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The Textile Museum

The Textile Museum is dedicated to furthering the understanding of mankind's creative achievements in the textile arts. As a museum, it is committed to its role as a center of excellence in the scholarly research, conservation, interpretation, and exhibition of textiles, with particular concern for the artistic, technical, and cultural significance of its collections. This mission is pursued through development and maintenance of collections, records, and a library, as well as through scholarly research, exhibitions, publications, and educational programs.

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Provincial Inca Tunics of the South Coast of Peru

Ann Pollard Rowe

Since the Incas originated in the highlands around Cuzco in what is now southern Peru, their textiles form a tradition contrasting with that of the coast. This contrast is most easily visible in men's tunics, which appear to have been the most important type of decorated textile, certainly for the Incas, and to a considerable extent also for the various coastal groups. These tunics have also fortunately survived in sufficient quantity for fruitful analysis. Their significance and survival are not coincidental, since men's tunics were part of the taxation and redistribution system of the Inca empire.¹

The Incas collected taxes in labor, and weaving was one of the types of labor in this system. There were male weaving specialists who wove garments as a tax, and wives of provincial officials also made a set of garments to be sent to Cuzco every year. In addition, those women chosen for religious service wove garments for sacrifices and for the ruler. Such garments could be worn only by persons who had received them from the Inca ruler as gifts and such gifts were not uncommon. They were given as a reward for service to the ruler in war or administration, to some of the people whom the Incas had resettled far from their homeland, and to nobles during the three times per year that they were required to present the materials collected as taxes in Cuzco.

One of the most obvious features distinguishing Inca men's tunics from those of the coast is that the Inca ones are longer

than they are wide (see figs. 1–3), about knee length, while coastal tunics are usually short, about waist length, and were worn with a decorative loincloth.

In addition, Inca tunic designs tend to be somewhat standardized and are thus also easily recognizable.² The most commonly found patterns are shown in figures 1–3. Their bold geometry contrasts with the generally smaller-scale coastal patterns which are often based on bird and animal forms. In addition, the overall design of the tunics is organized differently. For example, a stepped triangular area around the neck slit, as in figure 1, is a common Inca feature.³ Because of the relatively long proportions of Inca tunics, a change in patterning part way down, as in figure 2, or the use of a decorative band at about waist level, as in figure 3, are characteristically Inca rather than coastal design schemes. Coastal tunics of native styles tend to have decorative bands on the lower edges instead.

Certain technical features are also of great importance in distinguishing Inca from coastal tunics. Analyzing technical details is the most reliable way to distinguish different weaving traditions since unlike individual designs such features are common to all examples and are also less easily copied than designs. For example, Inca tunics are constructed with the warp direction placed horizontally as the tunic is worn, while coastal tunics are worn with the warp direction vertical. Moreover, the highland tapestry tradition exemplified in Inca tapestry was to use interlocked joins, a high thread count, and careful finishing of weft ends on both sides of the fabric so that the cloth is double-faced. In contrast, the central and north coast textile styles used slit tapestry weave and the style of the Ica valley on the south coast used interlocked tapestry that has many loose and floating weft ends on the back and so is not reversible. Tapestry from all parts of the coast also generally has lower thread counts than Inca tapestry. Inca tapestry warp yarns are commonly 3-ply S or 2-ply Z, in contrast to those of the coast which on the central and south coasts are usually 2-ply S and on the north coast are 2- or 3-ply Z. Inca tunics also often have a specific style of seaming and

Elements of Plane Symmetry in Oriental Carpets¹

Carol Bier

Design and Pattern in Oriental Carpets and Islamic Art

Historically, in the Islamic world from Spain to Indonesia, two-dimensional repeat patterns have served as primary means for organizing color and space. The ornamentation of architecture may involve the modifications of a two-dimensional pattern in its application to a three-dimensional surface. All of the uses of pattern, appearing as well on ceramics and metalwork, in book illumination, and textiles, rely upon the repetition of complex or simple designs to form overall repeat patterns of apparent complexity and intricacy. Yet within all the visual diversity and within the variability of regional traditions throughout the Islamic world, there is a common visual language expressed through pattern.²

Exemplifying beautifully the play of pattern, Oriental carpets fall within the realm of Islamic art. They offer a rich corpus of two-dimensional design, and an opportunity to study mathematical aspects of pattern.³

Patterns begin with symmetry. Patterns are created by the regular repetition of form according to the principles of symmetry. Patterns may please the eye and engage the mind—or they may be insistent, boring, distracting. They may harness our thought, or imprison our creativity. While the mathematical definition of a pattern may be absolute and precise, symmetry in nature is only ever approxi-

mate. Outwardly, man appears to be bilaterally symmetrical, yet no two sides of a person are exactly alike. It seems to be this appearance of symmetry in art as in nature—an approximation—that is most pleasing to the eye. Patterns with imperfections continually fascinate us because they confound and perplex us as they delight.

It is important to distinguish the difference between a *design* and the way its elements are repeated at regular intervals to form a *pattern*.⁴ By focusing on the difference between the analysis of design and the analysis of pattern in Oriental carpets,⁵ one may approach a better understanding of infinitely repeating patterns in Islamic art.

The typical layout for Oriental carpets is an oblong central field with an infinitely repeating pattern arbitrarily cut off by its borders. In looking at a carpet, what first attracts our attention, however, is its floral, geometric, or figural content. We tend to look for something to recognize: a floral form, a geometric shape, a meaningful symbol, or the representation of a figure. On a more abstract level, we may search for a lattice framework or grid. We may look, but not see that there is much more to what is not present in the oblong central field: the repeat pattern's implied continuation to infinity.⁶

An easily accessible example for the illustration of this point is that of a Turkmen bag face (fig. 1), in which the design consists of three octagonal medallions in a row, alternating with lozenge arrangements of small squares. This arrangement is often called a "three-gul" type in Western rug literature. To look at it from the broader perspective of pattern in Islamic art, the three medallions are but a small countable part of infinity. An infinitely repeating pattern is implied by the rows of octagons above and below the central group, which are only partially visible because the design is arbitrarily cut off by the borders.

Overall Repeat Patterns and the Notion of Infinity

The relationship of field pattern to border, as exemplified by this Turkmen bag face,

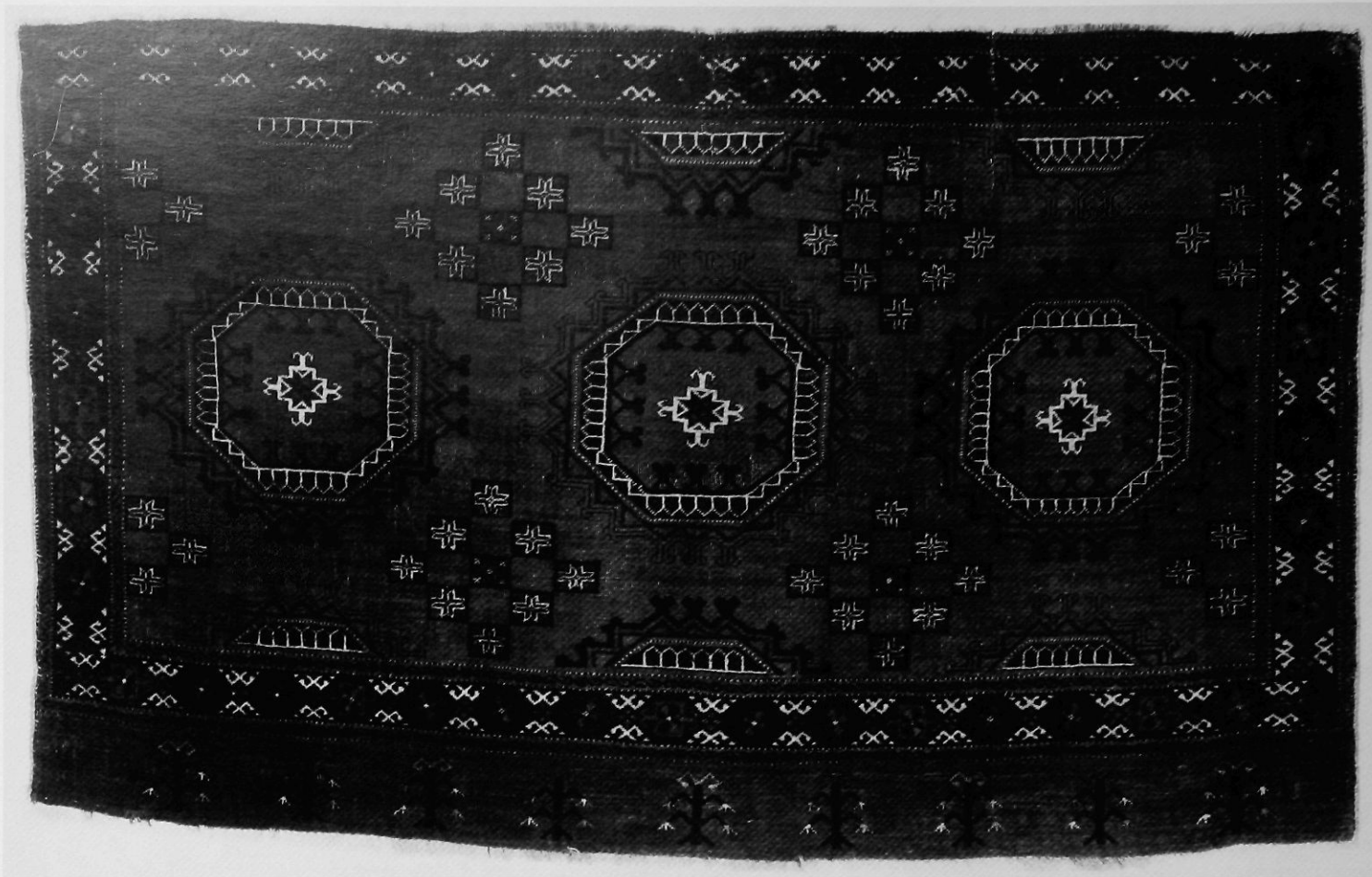


Fig. 1. Turkmen bag face, Central Asia, 19th century. 33.5 in. x 53 in. The Textile Museum 1980.13.4. Gift of Arthur D. Jenkins.

implies the relationship of infinity to finiteness.⁷ The expression of this philosophical notion in the visual arts has a history longer than that of Oriental carpets in the Islamic world, although it is in Islamic art that such expression has perhaps the greatest number of permutations. The notion of infinity bounded by finiteness was earlier explored in the geometric patterns of late Roman mosaic pavements in the first centuries of our era. A repeating pattern enclosed by borders is also evident in the layout and design of our earliest physical evidence for carpets: a carpet excavated at Pazyryk in Siberia, dating from around the time of Alexander the Great in the fourth century B.C.,⁸ and a carpet represented in the carved stone slab set before the throne in the palace of the Assyrian king at Nineveh in the seventh century B.C.⁹

Thinking about the limits of infinity is both confusing and enlightening, and offers a fresh perspective to the study of

Islamic art and the problems associated with interpreting and understanding overall repeat patterns in Oriental carpets and other media. Conceptualizing this notion may place Westerners in a more receptive mode to the study of pattern in the Islamic world.

Three graphic exercises enable us to visualize the theoretical relationship of infinity to finiteness. They are referred to in the literature as "Koch's Triangle" or "Koch's Snowflake" and the "Sierpinski Carpet" (together with its three-dimensional form, the "Menger Sponge").¹⁰ The first (figs. 2a-d) is related to the measurement of coastlines. Starting with a basic plane geometric form, an equilateral triangle, we are asked to add an equilateral triangle to the middle of each side, the side dimension of which is equal to one-third the side of the original triangle. This exercise may be repeated, with self-same incremental additions of triangles of ever smaller dimensions, to form an increas-

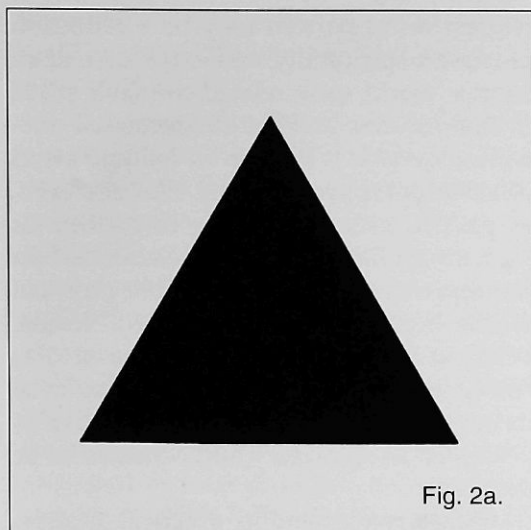


Fig. 2a.

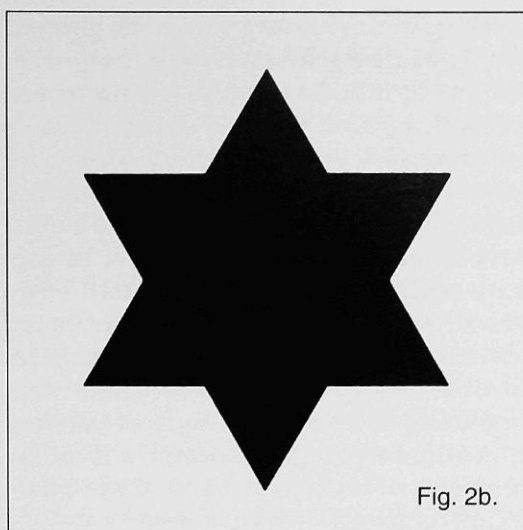


Fig. 2b.

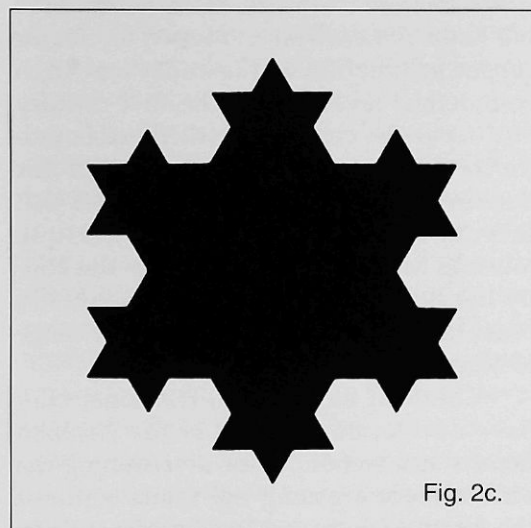


Fig. 2c.

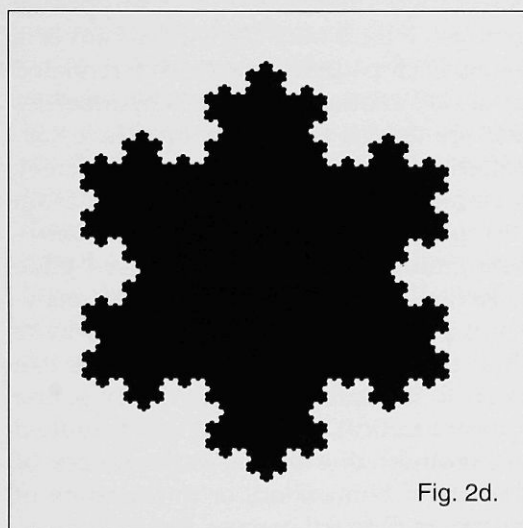


Fig. 2d.

Fig. 2 a-d. "Koch's Triangle" or "Koch's Snowflake." From *The Fractal Geometry of Nature* by Benoit B. Mandelbrot, W.H. Freeman, New York, 1982, by permission.

ingly long line enclosing an incrementally ever larger surface area. Eventually, one achieves an infinitely long line, enclosing a two-dimensional space which may yet be encompassed within the finite area circumscribed by a circle around the original triangle: the finite surrounding the infinite.

In the second instance, that of the "Sierpinski Carpet," the basic geometric form to start with is a square. We are asked to divide this square into nine equal parts, each side of which has a dimension exactly one third that of the original square. Then the middle square is removed. We are then asked to divide each remaining square into nine equal parts, and remove the middle square, and so on to its ultimate conclusion. If this exercise is performed using a three-dimensional form (a cube) to start,

the result (fig. 3, called the "Menger Sponge") would have an infinitely large surface area with zero volume.

While these exercises each demonstrate a literal bounding of infinity, the typical layout of Oriental carpets offers a conceptual bounding in which an infinitely repeating pattern is enclosed arbitrarily by the carpet's borders.

Scientific Understanding of Pattern

Pattern is perceived differently in the West today than it has historically within the Islamic world. In the West, the scientific analysis of pattern and its methods of construction are of relatively recent date and are related to the analysis of the growth patterns of crystals in two-dimensions.

Working in this century, the Dutch graphic artist, M.C. Escher, visually explored notions of infinity through kaleidoscopic forms that utilize repeated elements based on principles of symmetry to form patterns on the infinite plane. Topological aspects of Escher's periodic drawings have attracted considerable interest among both mathematicians and crystallographers.¹¹ Generally, the development of an understanding of crystallographic pattern in two- and three-dimensions, and the beginning of a scientific study of pattern, is credited to Evgraf Fedorov, a Russian physicist working at the end of the nineteenth century.¹²

Fedorov identified and described seventeen two-dimensional pattern types, or groups, which may be used to cover a plane. Each pattern group is differentiated from one another by various symmetries that are unique to each group. These seventeen pattern groups define (and thereby restrict) what may be generated from the four basic symmetry operations—translation, rotation, reflection, and glide reflection (discussed below). In the analysis of patterns in nature and art, no more than this number of pattern types can exist. To the uninitiated, this theory at first appears radical, especially when applied to the study of ornament in the history of the arts of humankind, or to the study of pattern in Oriental carpets. But it seems to have universal application, as recent studies show.¹³ And this limiting concept of only seventeen pattern types should seem no more startling than the fact that every circle no matter how small or how large has 360 degrees around its center, or that in every triangle, the sum of its interior angles is always 180 degrees, or that from a 26 letter alphabet all English literature proceeds.

Fedorov's work has been carried on by groups of physicists in the Soviet Union over the years, several of whom I had an opportunity to meet in Baku at the Second International Symposium on the Study of Azerbaijan Carpets and Carpet-making held in 1989.¹⁴ This group introduced me to the principles of crystallographic notation and showed me how these could be applied to the study of carpets.¹⁵

Muslim scholars suggest that the

expression of pattern may be a reflection of Islamic spirituality, and expressive of an Islamic world view related to man's place in the universe and the fundamental doctrine of *tawhid*.¹⁶ Pattern in Islamic art is often underappreciated by Western eyes, in part no doubt because traditions in Western art have more often elaborated on the representation of the visible physical world: human figures and vegetal forms. What is more often perceived and discussed is design rather than the results of its regular repetition (pattern), which is perceived as secondary and ornamental or decorative.

Mathematics and its practical application was hardly new to the Islamic world in the fifteenth century, from which time we have the earliest evidence for major carpet production at the court and high commercial levels. From the first century *hijri* (seventh century A.D.) there is evidence for the uses of mathematics for determination of the direction of *qibla* that orients both worshipper and mosque towards Mecca. Related to this is the ability to calculate direction, a skill needed in order to set forth on the annual pilgrimage to Mecca.

Celestial navigation, it seems, may have developed early on in the Arabian deserts as a technique for determining the direction for crossing the sands without the benefit of coastal landmarks, which had served for centuries to guide seamen in the Mediterranean in Roman times. The application of celestial navigation in the Mediterranean after the Arab conquests enabled sailors to veer off traditional coastal sightings to cross the open sea. In Baghdad under Abbasid rule from the eighth century A.D., schools set about translating Greek treatises on mathematics into Arabic, which precipitated a surge of philosophical discussion and theoretical criticism in Arab circles. The Arabs contributed to the international development of mathematical thought through the introduction of the notion of zero, and the concepts of zenith and nadir, along with the practical developments of trigonometric functions. Systems of proportion for Arabic calligraphic styles provide early evidence of the clear, careful and concise use of mathematical principles in art, fol-

lowed by the application of geometric pattern to three-dimensional architectural surfaces.¹⁷

An apogee in the use of pattern to ornament architectural surfaces was reached in the thirteenth-century Alhambra palace of the Nasrid rulers at Granada, where all seventeen pattern types have been documented in the glazed ceramic and carved stone and stucco ornamentation of walls, vaults, and ceilings.¹⁸ The patterns of the Alhambra were studied by the Dutch graphic artist, M.C. Escher, who copied them in 1936, and by others who have engaged in two-dimensional crystallographic analysis.¹⁹ The fact that all possible pattern types are present in this monument suggests a conscious and conscientious approach to experimentation with pattern if not to a theoretical exploration of the limits of pattern in nature and art.

An intuitive and conscientious approach to the potential for pattern in the Islamic world may clearly be recognized in both Oriental carpets and in the ornamentation of architecture as well as in the decorative arts. A predilection for pattern in art of the Islamic world precedes the scientific understanding of two-dimensional crystallographic patterns in Western developments of the past hundred years. It is, of course, out of the Islamic tradition that Oriental carpets serve to document in a woven medium a conscious play with pattern. Looking at design and pattern in Oriental carpets through the analysis of plane symmetries offers an opportunity to view mathematical principles with visual analogues.

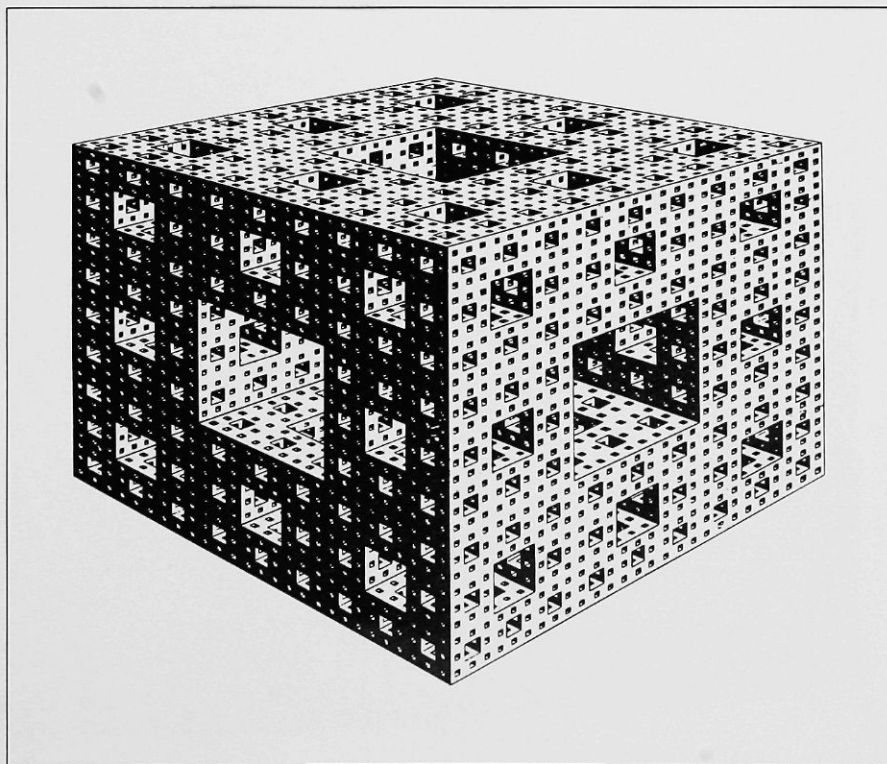
This is *not* to say that weavers or designers of Oriental carpets necessarily understood the mathematical principles which govern the growth of crystals in the two-dimensional plane, or that they were even consciously aware of scientific aspects of pattern more than in a practical sense. After all, cooks do not need to know the chemistry of heat convection on animal protein to scramble eggs. Nor were the Muslim weavers or designers of carpets necessarily aware that pattern and its exploration was a cultural inheritance which reflected Islamic notions of spirituality.²⁰ This *is* to say, however, that the same spatial laws and constraints that

govern the formation of two-dimensional crystallographic patterns also govern the processes of surface design. And in the same cultural milieu in which patterns of bounded infinity proliferated, spiritual concepts focus on unity and multiplicity as manifestations of the infinite and its limits.

Elements of Plane Symmetry

Patterns are generated by repetition of a design at regular intervals based upon the elements of plane symmetry. Symmetry implies a center: The principles of symmetry require an axis of reflection and translation, or a center of rotation. This can be a line serving as a vertical, horizontal, or oblique axis along which design elements are repeated or reflected, or it can be a point around which design elements are radially organized. The easiest way to analyze a pattern is to locate axes of symmetry (fig. 4). The viewer may then connect the points where vertical, horizontal, or diagonal axes intersect to define the unit of repeat and an underlying grid that structures the pattern. Theoretically, the unit of repeat may continue on the plane along each axis to infinity. In the case of the

Fig. 3. "Menger Sponge."
From *The Fractal Geometry of Nature* by Benoit B. Mandelbrot, W.H. Freeman, New York, 1982, by permission.



Turkmen bag face, the unit of repeat is defined by horizontal and vertical axes of symmetry, the intersecting points of which enclose a quarter of each medallion with its surrounding field including a quarter of each grouping of small squares. This unit of repeat is reversed along each axis, and but for the enclosing borders, it may continue indefinitely. Tracing the axes of symmetry which define each repeated unit, one may also recognize in the Turkmen bag face the underlying structure of a square grid (fig. 4).²¹

In the elements of plane symmetry, according to international norms established for the study of crystallography, there are but four symmetry operations. These are called: *translation*, *reflection*, *rotation*, and *glide reflection*, in addition to *identity*, a static position in which the original form of the design, the fundamental region, remains the same and unchanging. Using as an example an asymmetrical tri-

angle for a primary design element, let us explore how these symmetry operations may be performed.

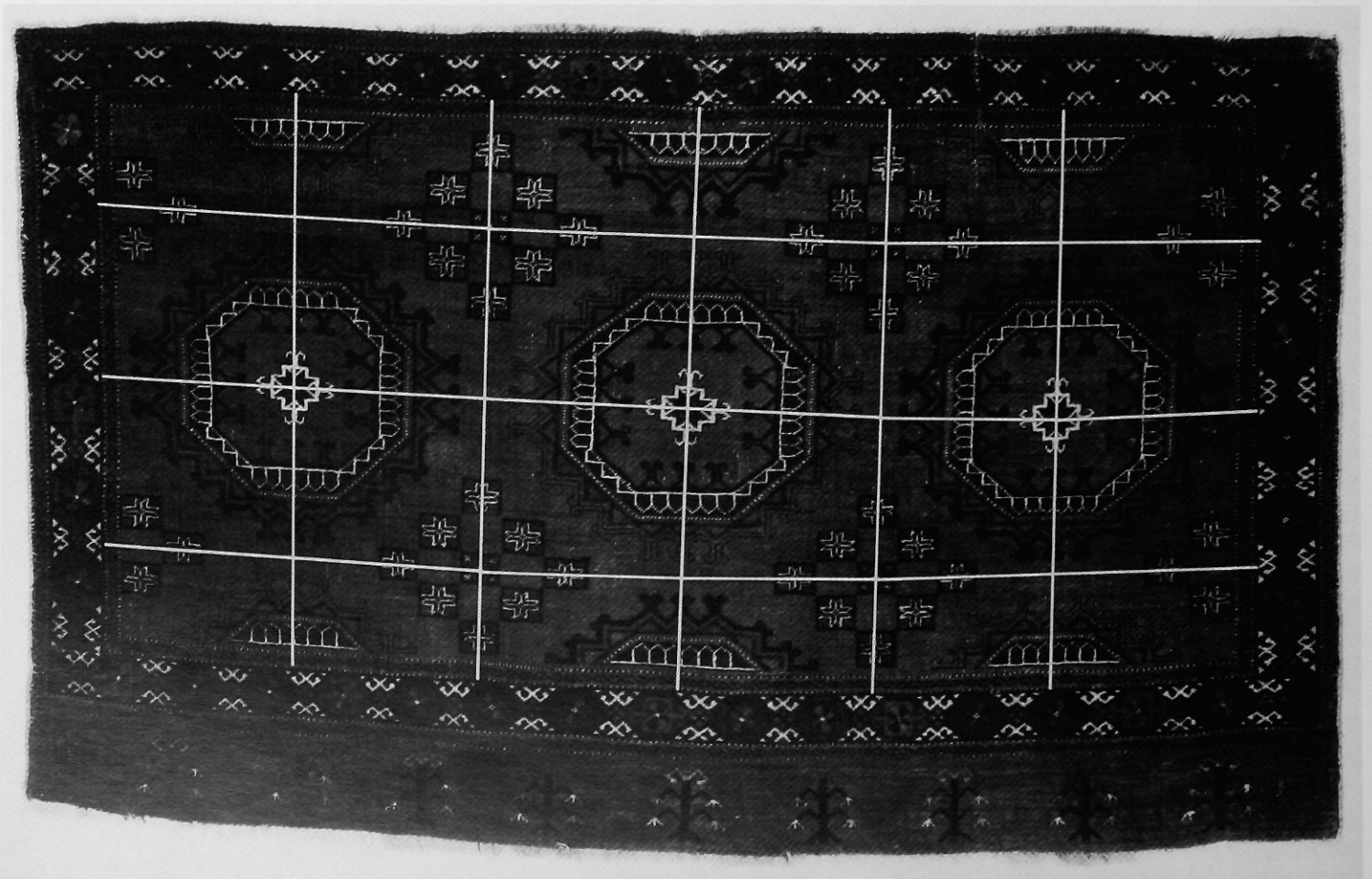
Identity, for the purposes of explanation, is an asymmetrical triangle of arbitrary determination (fig. 5).

Translation (fig. 6) repeats this unit with its surrounding field along either a horizontal or vertical line or axis to form a lattice structure or framework in which there are no gaps and no overlaps, to cover an entire (infinite) plane. This is sometimes called a "tiling." It results in a grid structure like that achieved by the laying of cobblestones, pavements, and some bathroom and kitchen tiles.

Tilings, or tessellations, which repeat regular polygons (squares, rectangles, rhomboids, and hexagons or equilateral triangles) are related to notions of "tight-packing" and to the formation of bee's wax in a hive.²²

Reflection (fig. 7) may occur along

Fig. 4. Same as fig. 1, showing axes of symmetry and unit of repeat.



either a horizontal or vertical axis and is a symmetry operation by which the right side is reversed to become the left, and the left side is reversed to become the right.

Rotation (figs. 8a–d) occurs around a central point. Dependent upon the mathematical properties of a circle, rotation may proceed in orders of two, three, four, or

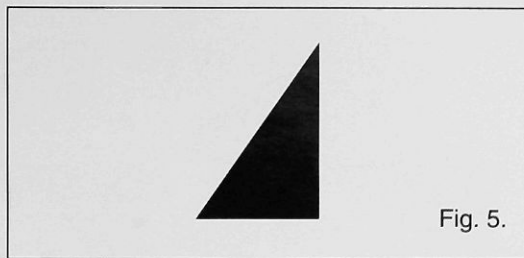


Fig. 5.

Fig. 5. *Identity*

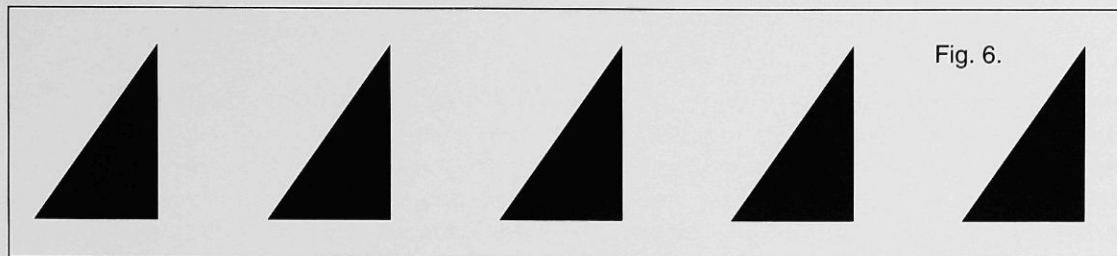


Fig. 6.

Fig. 6. *Translation*

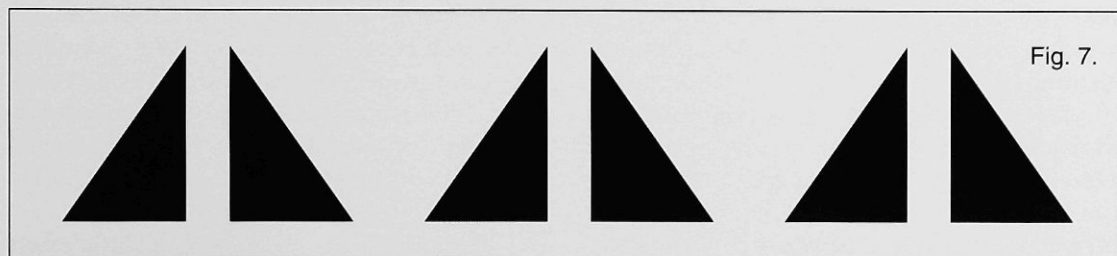


Fig. 7.

Fig. 7. *Reflection*

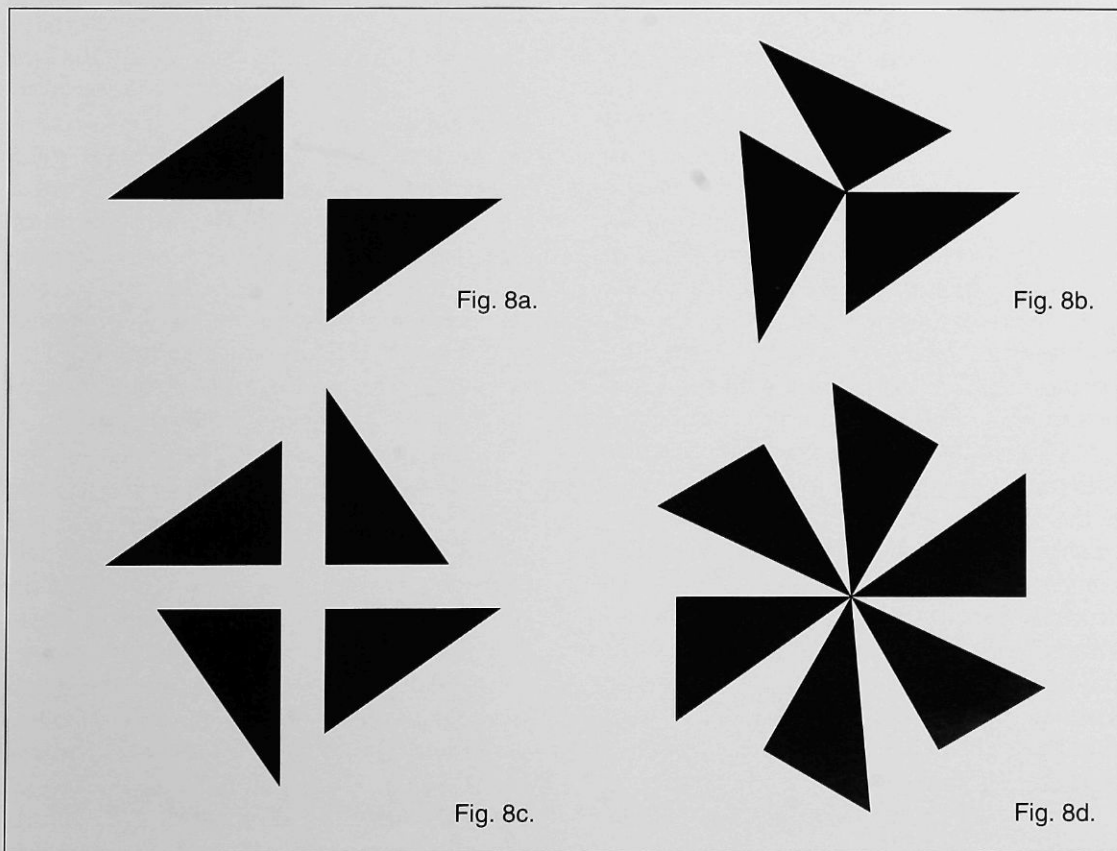


Fig. 8a.

Fig. 8b.

Fig. 8c.

Fig. 8d.

Figs. 8a–d. *Rotation*

a. Order 2 (180°)

b. Order 3 (120°)

c. Order 4 (90°)

d. Order 6 (60°)

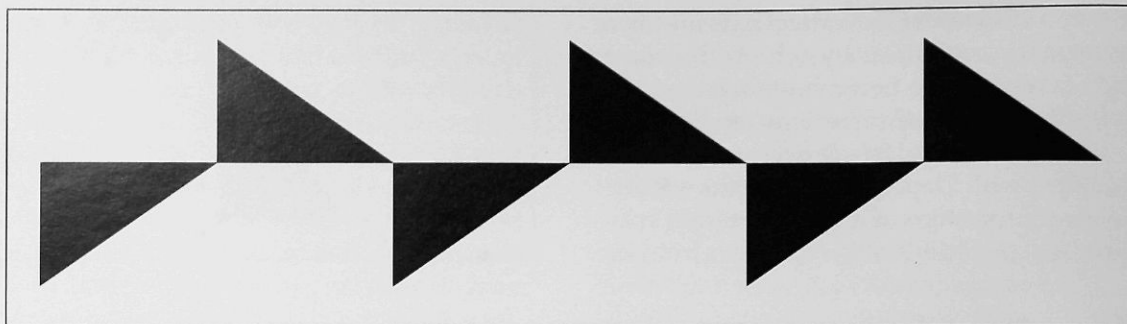


Fig. 9. *Glide reflection*

six, creating angles of repeat that are 180 degrees (fig. 8a), 120 degrees (fig. 8b), 90 degrees (fig. 8c), or 60 degrees (fig. 8d), respectively. Rotational symmetries of orders three and six may imply the existence of a hexagonal grid system. Rotational symmetries of orders two and four more often rely upon their translation into a rectangular grid which may be square or rhomboid.

Glide reflection (fig. 9) is effectively a displaced reflection or a reflected displaced translation. Performed along either the horizontal or vertical axis, the fundamental region (unit of repeat) is moved along the axis and repeated in reverse.

Our perception of these four symmetry operations, which form the basis for all pattern, may be complicated in a variety of ways. The most obvious, of course, is by the use of color. Pattern in a single color is simpler in appearance than pattern with the addition of one or more colors. Alternation of two colors further complicates a pattern. Likewise, the addition of secondary or tertiary motifs adds to the complexity of a pattern and creates considerably more variety in the permutation of pattern types. Finally, the visual representation of a third dimension complicates our perception of pattern, making it more difficult to analyze and comprehend. This is the case, for example, in the application of shading or by the adjustment of color to convey a pictorial quality as in European tapestries, or in the use of perspective creating *trompe l'oeil* effects in Roman mosaic pavements. The representation of interlace also suggests the presence of a third dimension, further challenging our perception of a pattern.

Symmetry and the Study of Oriental Carpets

If we apply plane symmetry analysis to the study of Oriental carpets we can analyze patterns by identifying the symmetry operations performed on particular design elements. Along with examples of translation, reflection, rotation, or glide reflection, we may find evidence for color alternation, the use of additional colors, supplementary design elements, the presence of shading or interlace to convey a visually-perceived sense of third dimension.

In carpets of the Yomut, color is often used to reinforce a sense of the diagonal. Guls in rows that are in staggered alignment are colored sequentially to create diagonal bands that at once guide the eye along an oblique axis, which takes precedence in our perception over the horizontal and vertical axes. The entire grid system may be seen as aligned to form a diagonal lattice (fig. 10). The actual unit of repeat may be defined from center to center of guls in two staggered rows, tracing the vertical and horizontal axes of repeat to the point where they intersect. The operations of plane symmetry used to create the gul are reflection and translation.

The Turkmen bag face (fig. 1) and the Yomut carpet (fig. 10) share in having the same pattern structure. They differ in the use of color banding (in the Yomut carpet) and the presence of a secondary motif (in the Turkmen bag face). Furthermore, rotational symmetry order 4 may be recognized in the bag face because of the equal number of knots per linear unit of measurement ($18\text{ h} \times 18\text{ v} = 324\text{ knots/square inch}$). Such is not the case in the Yomut carpet where the elongated guls result directly from unequal knot counts hori-



Fig. 10. Yomut main carpet, Central Asia, 19th century. 126.5 in. x 73.5 in. The Textile Museum R37.5.1. Acquired by George Hewitt Myers.

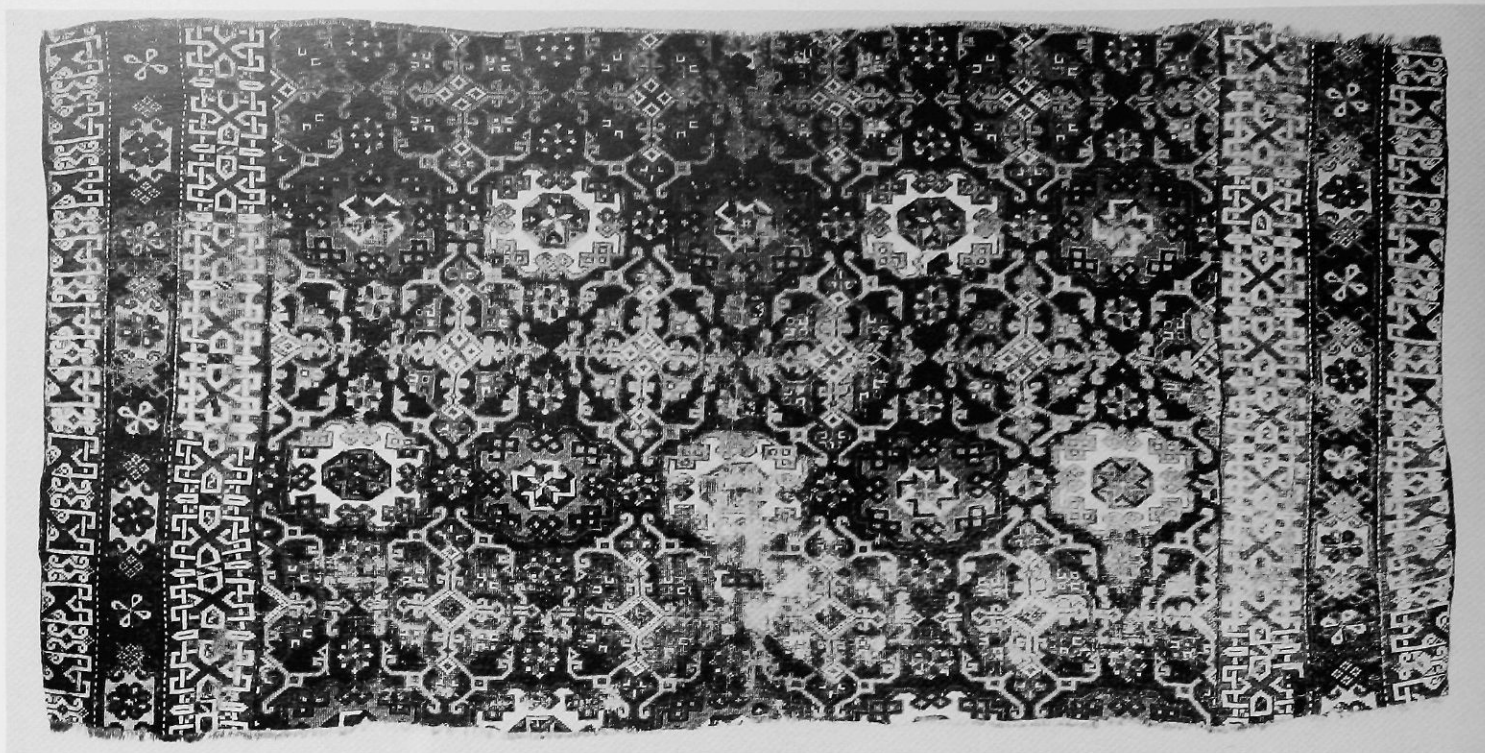


Fig. 11. Small-patterned Holbein carpet fragment, Turkey, late 15th/early 16th century. 93.5 in. x 46.5 in. The Textile Museum R34.17.2. Acquired by George Hewitt Myers in 1927.

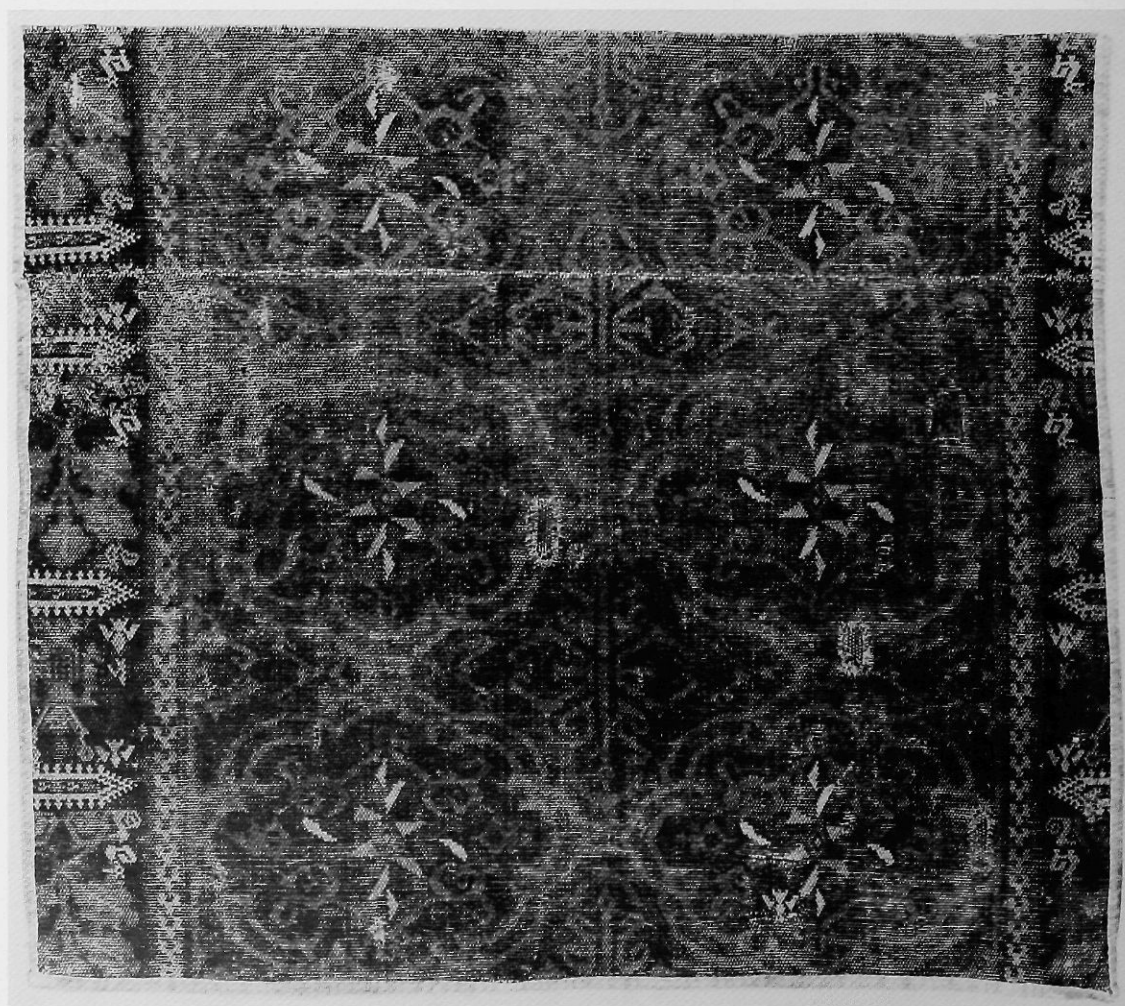


Fig. 12. Spanish carpet fragment (runner), Nasrid, 15th century. 32 in. x 42 in. The Textile Museum R44.2.6. Acquired by George Hewitt Myers in 1915.

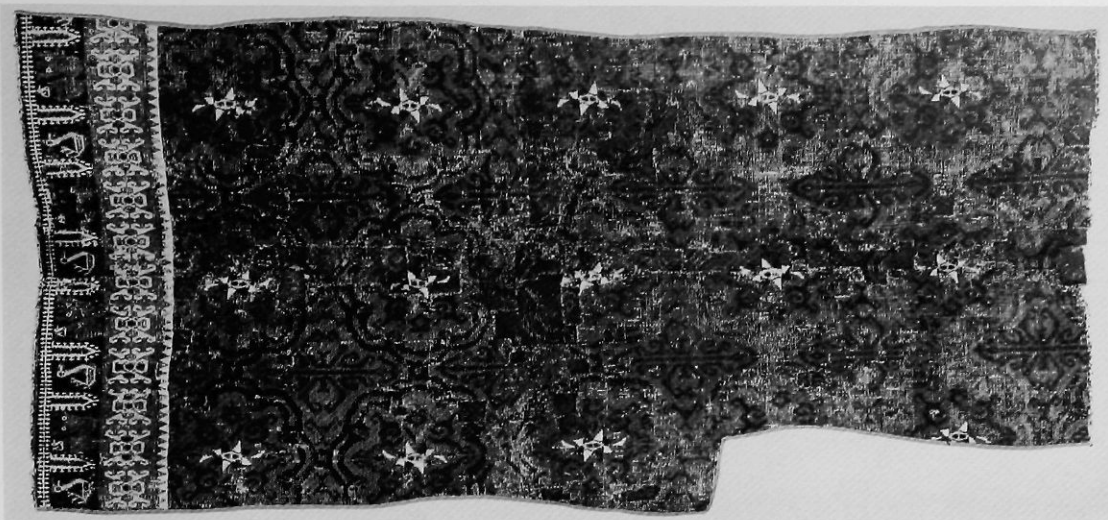


Fig. 13. Spanish carpet fragment, Nasrid, 15th century. 33 in. x 73 in. The Textile Museum R44.2.3. Acquired by George Hewitt Myers in 1931.

zontally and vertically (approx. 14 v x 17 h = 238 knots/square inch).

A small-pattern Holbein fragment (fig. 11) exhibits the same pattern structure. Compared to the Turkmen bag face and the Yomut carpet, its pattern appears even more complicated because of the addition of interlace as well as secondary and tertiary motifs and color alternation in each of the primary guls. A related use of interlace, less complicated in our perception of it for its monochromatic presence in green, is seen in two Spanish fragments (figs. 12 and 13). In all three of these examples, reflection and translation are evident. In the Spanish fragments, rotational symmetry is suggested, but analysis of the pattern reveals several extra rows of knots in each unit block which are not replicated. We may also see a contrast here between the nearly perfect circles achieved in the Spanish carpets, in which an equal number of knots are employed horizontally and vertically (11 h x 11 v = 121 knots/square inch), and the elongated guls in the Turkish fragment, in which the knot count is not equal (8 h x 9 v = 72 knots/square inch).

Centrally planned carpets may not appear to have infinitely repeating patterns at first glance. Closer analysis, however, reveals the presence of elements of plane symmetry. The Safavid carpet (fig. 14) and Mamluk carpet (fig. 15) exhibit elements of plane symmetry which repeat to form overall repeats limited only by the carpets' borders. In the case of the Safavid

carpet the system of overlaying medallions partially obscures a view of the underlying system of vines with leaves and flowers, which utilizes reflection to create an overall repeat pattern. The medallions themselves are organized radially around a central point. Within the radial arrangement may be recognized an order four rotation,²³ with the unit of repeat incorporating reflection within each quarter of the superimposed medallions. An identical layout may be recognized in the Mamluk star medallion, above and below which lie three translations of a square unit that itself incorporates reflection within an order four rotation. Such radial designs in carpets have often been related to both the two-dimensional patterns in book illumination and to the applied geometry of repeat systems in architectural ornamentation.²⁴

The study of symmetry in a carpet may, however, also reveal the presence of asymmetry beyond that of color alternation and similar play with pattern. Such asymmetry may be unintentional, deriving from human error in the process of handloom weaving. Or, it may reflect intentional transformation on the part of weaver and/or designer. For example, in the case of an inscription within a pattern, the asymmetry is clearly intentional, for it represents an accommodation to visual content which is explicitly expressed by means of the inscription. Inaccuracies in a pattern, on the other hand, may reflect the purposeful introduction of imperfection



Fig. 14. Safavid carpet,
Iran, Tabriz or Isfahan, late
16th/early 17th century.
83 in. x 52.5 in. The Textile
Museum R33.1.3.
Acquired by George
Hewitt Myers in 1924.

on the part of the weaver.²⁵

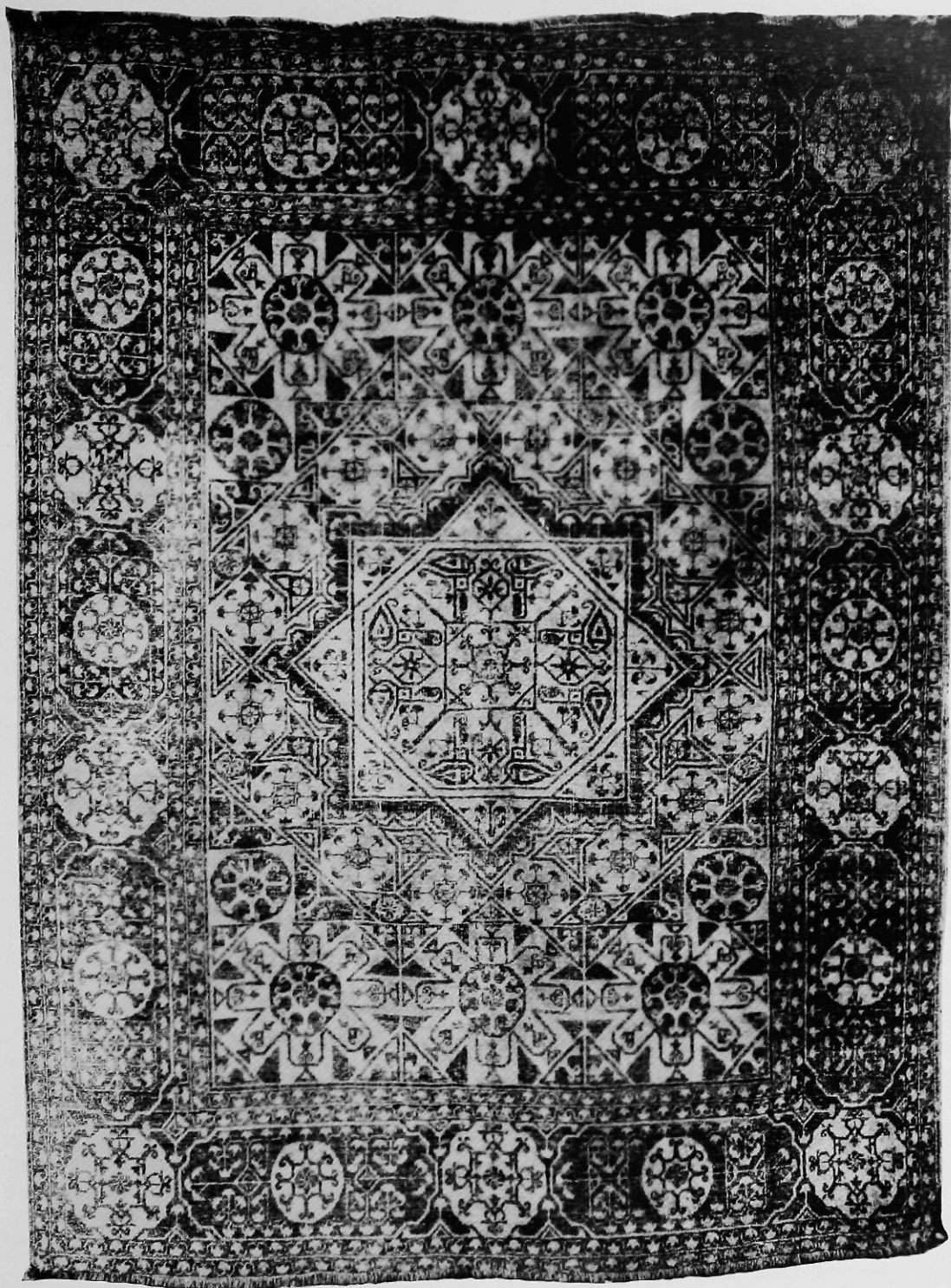
Complex infinitely repeating patterns are relatively easy to construct graphically because they rely simply on the use of a compass and straight-edge. Their constructions may be simple, even if when completed, the results may be difficult to analyze visually or mathematically. Yet computerized scanning of the nine carpets displayed in the 1990–1991 exhibition "Visions of Infinity" at The Textile

Museum revealed additional information about the differences between pattern in theory and practice.²⁶ Our intent was to analyze patterns in Oriental carpets so as to regenerate them accurately by computer for educational purposes in the context of gallery display. But discrepancies in the actual knotting made this task impossible. The patterns of these nine carpets defied computer regeneration because of idiosyncracies in every apparent repeat.²⁷

Fabric Structure, Knot Density, and the Perception of Pattern

Design and pattern in Oriental carpets is retained in the surface plane, conveyed by color alone. The three-dimensional structure of pile carpets, therefore, need not be considered in relation to the construction of pattern. Knot density, however, is an important factor in our perception of pattern. While color derives from the placement of the knots (which structurally are cut segments of supplementary wefts wrapped around adjacent warps), the higher the knot density in relation to the size of a unit of repeat, the more approximate may be our perception of a curved or diagonal line. Related to knot density is the position of adjacent warps. Depressed warps (warps on two levels), with either a symmetrical ("Turkish" or Ghiordes) or asymmetrical ("Persian" or Senneh) knot, produce a denser structure that yields a closer approximation of a diagonal or curve in spite of the modular stepped units which form the rectilinear matrix.²⁸ The perception of curves and diagonals is also a function of viewing distance.²⁹ In all of these instances, the actual pattern is conveyed visually by surface color which does not interact with fabric structure. This is in sharp contrast with the relationship of fabric structure to design and pattern in woven textiles.³⁰

Associated with interrelationships of design and structure, however, there is an additional factor operative in rug-weaving which warrants close consideration. This is the ratio of horizontal to vertical linear knot counts. Only if this ratio is 1 can rotational symmetry order four be conveyed visually in a repeated pattern (see note 23). A ratio of greater than one or less than one



will yield compressed or elongated designs set within a rectangular grid. A square grid, as in the case of the Pazyryk carpet and most Mamluk carpets, can be achieved when the knot count per linear unit of measurement is the same along both the vertical (warp) and horizontal (weft) axes. If horizontal and vertical knot

counts per linear unit of measurement are not equal, the results of weaving the same number of knots along each axis to form a design will result in a compressed or elongated form, as is the case with numerous late Turkmen rugs as well as in many commercial products of the nineteenth century from Turkey, Iran, and the Caucasus.

Fig. 15. Mamluk carpet, Egypt, Cairo, 15th century. 70 in. x 52.5 in. The Textile Museum R16.1.1. Acquired by George Hewitt Myers in 1953.

Beyond Oriental Carpets: Analysis and Perception of Pattern

By utilizing principles of two-dimensional crystallographic analysis to study Oriental carpets, we are better able to "see" pattern. Analyzing design and pattern to determine the ways by which design elements are manipulated to form patterns provides a means for exploring visual relationships. It provides a tool for our eyes to look and for our brains to see.

Minor differences within pattern, even if only slight, seem to make carpets more interesting. Imperfections make the patterns less insistent and more playful; hence, removed from the possibility of accurate predictability, they relieve the prospect of boredom. It is this aspect of pattern that seems to be operative upon perception: The appearance of symmetry, or its approximation, seems far more pleasing than perfect symmetry; imprecision seems more interesting than precision in terms of visual appreciation. It may be precisely the imprecise that most pleases the eye and teases the brain. This judgment, if accurate, has powerful implications for ongoing design and production of carpets for commerce. For although the technology for making Oriental carpets has remained close to its historical antecedents of hand-knotting upon a vertical or horizontal loom, both the design processes, and the mechanisms for transferring designs, have been transformed by computerization. Too often the achievements of this increased technological potential for precision in pattern-making have resulted in commercial carpets with a regularity of pattern that is too insistent.³¹

This article has addressed the elements of plane symmetry in the study of pattern in Oriental carpets. It is by the juxtaposition, manipulation, and repetition of these four basic symmetries that patterns emerge. Groups of plane symmetry are operative in creating the appearance of complexity in overall repeat patterns, a larger subject to be addressed in a sequel to this presentation.

Note: Visual analysis of pattern is a process requiring patience and curiosity on the part of the viewer. It is an analytical method that may be applied to any pattern regardless of cultural context, date or chronology, aesthetic or medium: It has a universality of application. Initially, the process of "reading" a pattern is not self-evident. But once learned, the effort is worthwhile and enjoyable because such visual awareness adds a new dimension to our perception of the world.

About the author

Carol Bier is Curator for Eastern Hemisphere collections at The Textile Museum. She received her graduate training in Near Eastern art and archaeology at the Oriental Institute, University of Chicago, and at the Institute of Fine Arts, New York University, and she has participated in archaeological field research in Iran, Turkey, Egypt, and Syria. Ms. Bier has published widely, lectured throughout North America and abroad, and has organized numerous museum exhibitions of Oriental carpets, Islamic textiles, and related arts.

Notes

1. An earlier version of this paper, "Overall Repeat Patterns, Oriental Carpets, and Islamic Art," was presented to the VIth International Conference on Oriental Carpets held in San Francisco in November 1990. For revision, I wish to acknowledge the critical comments of Betty Lou Hummel, Susanne Newberry, Mimi Wheeler, Lorna Carmel, Walter Denny, and Jerry Cooper. I am particularly indebted to Harry Bixler for lending a mathematician's eye and mind to the editorial process. Research for this study was undertaken during the planning phase of the exhibition, "Visions of Infinity: Design and Pattern in Oriental Carpets," on view at The Textile Museum, 19 August 1990–24 February 1991.
2. Books that document and explore pattern in Islamic monuments include Bourgoin 1973 [1879], Burckhardt 1976, Critchlow 1976, El-Said and Parman 1976, and Wilson 1988. For more general approaches to the study of pattern and ornament, respectively, see Albarn *et al* 1974 and Gombrich 1979, both of which discuss Islamic works at some length.
3. Mathematical approaches to the study of pattern, based upon two-dimensional crystallographic analysis, form the basis of the works by Elliott 1990, Grünbaum and Shephard 1986, Stevens 1981, and Washburn and Crowe 1988; for Islamic monuments in particular, see Bixler 1980. For other non-mathematical approaches to the study of pattern in Oriental carpets, see Pinner 1988, Ellis 1967, Erdmann 1967, Spuhler 1978, and Beattie 1986.
4. This is a subject I first addressed in a paper presented to the Vth International Conference on Oriental Carpets, held in Vienna in September 1986 (Bier 1987, pp. 97–106), where I compared the graphic structure of "dragon" and "vase" carpets, describing the design as a two- or three-plane lattice enclosing stylized animals or blossoms, and describing the pattern as a system of columnar units of repeat.
5. Bier 1987, figs. 2a,b; Bier and Carmel 1990.
6. For discussion of patterns and notions of infinity in relation to Islamic spirituality, see particularly al-Faruqi and al-Faruqi 1986 and Nasr 1987.
7. Notions of infinity and its boundedness are concepts explored among several of the ancient philosophers; see Moore 1990 (reviewed by Roger Penrose in *Times Literary Supplement* October 26–November 1, 1990, pp. 1155–1156), for which reference I am indebted to Harry Marks. Today these issues are once again the subject of scientific investigation attracting public notice (see also Bronowski 1973). The new field of fractals is related to the notion of infinity bounded by finiteness (Mandelbrot 1982), as are studies of chaos and its scientific analysis which has also incurred popular interest (Gleick 1988).
8. Robinson 1990; Böhmer and Thompson 1991.
9. Albenda 1978.
10. All three examples are described and illustrated in Gleick 1988, pp. 98–102.
11. Coxeter *et al* 1986; MacGillavry 1965; Schattschneider 1990.
12. Coxeter 1969, pp. 50 and 279.
13. Washburn and Crowe 1988; Elliott 1990.
14. Among whom was Mamedov, see Mamedov 1986.
15. Earlier, Dr. Glenn Fulmer, who attended my introductory course on Oriental carpets at Johns Hopkins University School of Continuing Studies in Baltimore, advised me to look at principles of international crystallography and the elements of plane symmetry to analyze pattern in Oriental carpets. To him I also owe a debt of thanks.
16. See Critchlow 1976, al-Faruqi and al-Faruqi 1986, and Nasr 1987.
17. For an excellent summary of the Arab study of geometry, see Souissi 1982.
18. Müller 1944 discredits the frequently cited statement that all seventeen pattern types are present at the Alhambra. See Grünbaum and Shephard 1986, p. 56 and n. 19 below.
19. M.C. Escher's experience of the Alhambra is referred to in numerous works (see Gardiner 1961, Coxeter 1969, p. 58, Bronowski 1973, pp. 168–176, Grabar 1978, pp. 196–197, Grünbaum and Shephard 1986, pp. 1–3, and Elliott 1990, p. 3). For an analytical study of the ornament of the Alhambra in relation to group theory, see Müller 1944 and n. 18 above.

20. Study of the role of Sufism (mystical dimensions of Islam) and its relationship to carpet-weaving would benefit our understanding of these aspects of design and pattern in Oriental carpets. In particular, the Naqshbandi and Khaksari orders are known to have had both practical and metaphorical connections with weaving.

21. The definition and basic concepts associated with patterns covering a plane are referred to mathematically in the context of two-dimensional crystallography. For introductory discussion, see Coxeter 1969, pp. 29–34 and 39–61, Grünbaum and Shephard 1986, pp. 1–57, and Stevens 1981.

22. Grünbaum and Shephard 1986.

23. In the course of my research, it became clear that rotational symmetry order four in a carpet requires an equal linear knot count horizontally and vertically. Equal linear knot counts are also required to enable a square-grid to transfer effectively from cartoon to carpet. The knot count of the Safavid carpet (fig. 14) is $11\text{ h} \times 11\text{ v} = 121$ knots/square inch. The knot count of the Mamluk carpet (fig. 15), is $13\text{ h} \times 13\text{ v} = 169$ knots/square inch. Typically, court-produced carpets reflect the care and attention to both design and quality control that is required to achieve these results. It is important to note this aspect of carpet production, too often neglected in rug studies: knot density itself is less significant than the ratio of horizontal to vertical knot counts (see above, *passim*).

24. El-Said and Parman 1976.

25. It is more likely in the larger view of Islamic art that these imperfections reflect a very deep appreciation of pattern within the cultural her-

itage of Islam, perhaps related as well to an appreciation of the concepts of *zahir* (Ar. "back," or "surface appearance") and *batn* (Ar. "stomach," or "essential reality"), notions addressed in Hodgson 1960.

26. The Textile Museum acknowledges the generous efforts of Verda Elliott, a master weaver using a 16-harness loom with computer-generated patterns she programs, and her associate, Suzanne Dalton. We also acknowledge the assistance of George McConnell of The Tool Box, and S. Upton Jenkins, President, Universal Color Systems, Fairfax County, Virginia, a company specializing in development and applications of software for commercial weaving.

27. George M. Rogers, III, a graphic artist and Public Information Officer at The Textile Museum, attempted to reconstruct the pattern of the Mamluk carpet (TM R16.2.1, see fig. 15) by hand and encountered similar difficulties (personal communication).

28. Bier 1992, p. 114.

29. Bier 1992, p. 114.

30. Woven textiles present a special case for pattern analysis because of the direct relationship of pattern to woven fabric structure: overall repeat patterns are created by the process of weaving and structurally integrated with the fabric itself. Although we may perceive the pattern as two-dimensional, in actuality it represents a three-dimensional structure (Grünbaum and Shephard 1984).

31. With specific reference to carpets produced in the Caucasus at the beginning of *perestroika*, see Bier 1991, p. 26.

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